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Equitable Pricing of Episodes of Care in a Cluster-Based Bundled Payment System

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Abstract

Most of the individuals in the United States are concerned about healthcare affordability and rising healthcare costs. The prevalent healthcare cost reimbursement system, Fee-For-Service (FFS) has been deemed as a key driver for increasing healthcare costs. Bundle payments (BP) has been suggested as an alternative to replace FFS and has shown to reduce the rising healthcare costs. Under BP, the expected set of services involved in treating a diagnoses, or episode of care, is reimbursed by a single payment. We propose a systemic pricing of multiple diagnosis under a Cluster-Based Bundle Payment system (CBBP), where for a given diagnosis, groups of encounters with homogeneous service patterns are reimbursed by a single price. Through a two-stage multi-criteria optimization model, we systemically price clusters of encounters to make highly critical episodes of care more affordable by collecting more revenue from less critical clusters across all episodes of care while mitigating the overall financial risks which can facilitate the implementation of BP and CBBP on a larger scale. The criticality of an episode of care and their clusters of encounters is obtained via Analytic Hierarchy Process (AHP) as a function of their average costs levels, average overpayments, and number of encounters. We compare the results of our proposed methodology with a benchmark model where pricing is done using the mean FFS cost for the 153 most expensive episodes of care in the Greater Rochester area for 2007. The proposed methodology offers a systematic approach for reimbursing episodes of care depending on their criticality, and improving the affordability and lowering of overpayment costs across any given range of episodes of care.

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1. Introduction

The per capita expenditure on healthcare services in the United States is higher than in any other industrialized country in the world [1]. According to the 2016 National Health Expenditure data [1], the per capita expenditure on healthcare services in the United States ($10,348) is approximately 31% higher than Switzerland ($7,919), which is the next highest per capita spender on healthcare services. The national healthcare expenditure in the United States increased to $3.3 trillion in 2016, a 4.3% increase from 2015, accounting for 17.9% of the Gross Domestic Product [2]. The Centre for Medical and Medicare Services (CMS) has projected the healthcare spending in the United States to rise 5.5% annually from 2017 to 2026 and will account for nearly 19.7% ($5.7 trillion) of the U.S. economy by 2026 [3]. According to a 2017 Gallup survey [4], 57% of the individuals in the United States are concerned about healthcare affordability due to their rising costs. As a result of the increasing healthcare costs, in 2017 insurance premiums rose by 3%, a growing financial burden for middle-class families [5, 6]. Despite the high levels of spending on healthcare services, the United States ranks lowest in terms of life expectancy and with the highest infant mortality rates among other high-income countries [7]. The increase in healthcare spending has been attributed to multiple factors including an increase in population, rising price of medical services, increased spending on chronic health conditions like diabetes and heart diseases, administrative costs and the way in which healthcare costs are reimbursed [7].

The current most popular method of medical reimbursement, the Fee-for-Service (FFS), has been regarded as one of the major contributors to the rising healthcare cost in the United States [8]. Under FFS, a hospital (provider) is paid by an insurance company (payer) for every service provided to a patient (beneficiary). FFS incentivizes volume of services and does not encourage healthcare coordination, integration, and management of healthcare delivery [8]. This encourages the providers to offer higher than the required number of services or opt for a more costly treatment option than an equally effective affordable treatment [9].

The bundled payment (BP) system has been identified as an alternative method of medical reimbursement that could potentially reduce the healthcare costs in the United States [10]. Under the bundled payment method of reimbursement, a payer offers a single payment for all services provided to a patient during an episode of care. An episode of care consists of the expected set of services required to treat a patient for a given primary diagnosis. Providers participating under the BP system receive a pre-defined monetary amount for the services provided to a patient for a given medical condition. Under the BP system, a provider can incur losses if the treatment cost exceeds the single pre-defined payment amount. The provider can increase its profit by offering services at a lower price than the pre-determined single price, thereby encouraging providers to ensure better healthcare coordination, improving quality of care and identifying opportunities to eliminate avoidable services and unnecessary readmissions to reduce the total treatment costs.

However, the implementation of the bundled payment system poses several challenges [11]. First, it is difficult to characterize an episode of care for a given primary diagnosis. The inclusion of services in an episode of care is dependent on the patient's health condition which is heterogeneous since every individual differs in age, gender, the severity of the illness and comorbidities. A clear start and end date for an encounter are necessary for defining an episode of care, which is highly subjective and varies among providers. Because of the ambiguity in defining an episode of care, an estimate of the single payment may result in lower incentives for providers to offer expensive and complex services. Differences in quality of care offered by different providers may impact the total cost for a given episode. For patients suffering from complex medical conditions and thus requiring a high level of care, the single payment price may not be sufficient to cover the overall expenses. Therefore, under the BP system, having a single payment for an episode of care can introduce financial risks of underpayment and overpayment for both the providers and the payers, respectively.

To address the challenges faced in the characterization of an episode of care, Zhang et al. [12] and Singh [13] propose a cluster-based approach for characterizing an episode of care where the expected set of services representing an episode of care is retrospectively determined from the analytical and cluster methods applied to claim records. In a cluster based bundled payment system encounters are clustered based on similar procedural pattern associated with a primary diagnosis and assigned a single price per homogeneous cluster of encounters. Zhang et al. [12] uses a single clustering stage of grouping encounters directly associated with diagnosis of interest whereas Singh [13] extends the clustering stage of grouping encounters associated with diagnosis most likely to precede and follow the diagnosis of interest. Additionally, Singh [13] implements a second stage classification step over encounters that fuses non-procedural information and results from the clustering stage to generate more homogeneous clusters of encounters. The cluster-based bundled payment (CBBP) minimally relies on expert input and can facilitate the adoption of bundled payments.

Despite demonstrating the effectiveness of clustering in characterizing an episode of care proposed by Zhang et al.[12] and Singh [13], these studies do not explore pricing opportunities in the CBBP. Zhang et al. [12] and Singh [13] simply assume that in a CBBP, the reimbursement price for each cluster of encounters within an episode of care should correspond to the mean FFS cost of the encounters of each cluster. Using the cluster mean as the single price for clusters of encounters ensures minimum cost variation, however, it does not necessarily increase the affordability for medical services or reduce risk of overpayments. In this study, we consider critical episodes of care and critical clusters of encounters as those that involve a high risk of average overpayments, have a high number of encounters and a relatively high average cost under the current FFS system. Pricing of clusters by other than the mean cluster cost can offer an opportunity to make CBBP a more affordable system. This study aims to price clusters of services for various episodes of care to reduce the overall risk of overpayments and underpayments and increase the affordability for critical episodes of care and clusters of encounters while maximizing the total surplus of the payers in a CBBP system.

Most of the bundled payment and cluster based bundled payment models which have helped in lowering healthcare costs or lowering financial risks have been implemented on a single episode of care. The result of such an implementation does take into account the effect of the overall healthcare system. In our study, we propose a systemic pricing approach where we price multiple episodes of care to make highly critical episodes of care more affordable by collecting more revenue from less critical clusters across all episodes of care, while also mitigating the overall financial risks, which can facilitate the implementation of BP and CBBP on a larger scale.

In particular, we aim to answer the following research questions: a) What are the effects of a systemic pricing approach on the overpayment and underpayment risks, and on affordability of critical clusters under a CBBP system?

We propose a three-step approach to price clusters of encounters for episodes of care under the CBBP. First, we generate the clusters of services for a given episode of care by using characterizing approach proposd by Singh [13]. The study then identifies critical episodes of care and critical clusters of encounters by factoring in the average overpayments, total number of encounters and the average cost per encounter for an episode of care, as a consequence of their clustering. Third, a two-stage linear programming model is proposed to determine the single reimbursement price for each cluster of encounters. We first solve the mathematical model to allocate a total budget across an episode of care under consideration. We then use the total budget allocated to an episode of care as determined from the previous step and solve a second mathematical model for determining the reimbursement price for clusters of encounters within the episode of care.

The single payment for clusters of encounters obtained from the mathematical model is used to calculate total overpayments, total underpayments, and analyze the affordability of critical clusters under the CBBP. The results are compared with those resulting from using the mean cluster cost as the single payment price for each cluster of encounters in CBBP.

2. Literature Review

There have been several studies that have shown that the bundled payment system is an effective method of reimbursement for reducing healthcare costs. In this section, we discuss several bundled payment models and the challenges associated with their implementation.

In 1983, Medicare's Inpatient Prospective Payment System (IPPS) proposed a single payment for inpatient care services [14, 15]. IPPS not only slowed the increase in Medicare spending but also reduced the length of stay [14, 15]. The single reimbursement price was adjusted based on the patients' medical condition relative to the average Medicare case, geographical factors, wage index and other market conditions. Under the IPPS, except for seriously ill patients, the provider was paid a flat fee for the given episode regardless for the actual services provided to the patient. The formula to calculate the single price under this model is not generalizable since it requires many adjustments to address outliers and to account for the federal budget constraints [16].

In 1984, Texas Heart Institute developed a fixed pricing plan known as the CardioVascular Care Providers covering all procedures, including physician fees and hospital fees for cardiovascular surgery [17]. The system was not only able to lower healthcare costs but also improved the quality of care administered to patients. A set of standardized tests and services defined for patients undergoing cardiovascular surgery was used to calculate the fixed price under the CardioVascular Care Providers model [17]. However, this pricing model did not consider the complexity of the patient's health condition and the incidence of comorbidity.

In 1991, the Health Care Financing Administration adopted the bundled payment system for heart bypass surgery under which the providers were reimbursed with a single payment covering only the inpatient stay. The implementation witnessed savings of $17 million on bypass surgery across four participating hospitals in Boston, Atlanta, Ann Arbor, and Columbus [18]. The negotiated single price was based on two separate estimates of the provider and of the physicians in which they used their own discount rates to estimate the single payment price for bypass surgery [18]. However, feedback from the hospital staff suggested that the quality of care was aggravated because of the high financial risks incurred under the BP system [19].

In 2006, Geisinger Health Systems through its bundle payment system known as Proven Care helped lower hospital costs by 5% for all procedures related to Coronary Artery Bypass Graft (CABG) [20]. The episode cost included the cost of hospitalization and services offered within 90 days of being discharged. The bundle included pre-operative services, hospital and professional fees, and services offered post discharge. Since the Geisinger Health System integrate a payer and provider and it could more easily align the incentives between them to facilitate the implementation of its bundled payment model.

In 2006, the Health Care Incentives Improvement Initiative (HCI3) implemented the PROMETHEUS bundled payment model that used evidence-informed case rates to determine a single payment for an encounter for chronic and complex medical conditions like acute myocardial infarction and congestive heart failure [21]. The price was adjusted based on the severity and complexity of the patient's health condition and the providers were rewarded for providing high-quality care [21]. A study conducted by Navathe et al. [22] showed that the participating provider under the PROMETHEUS bundled payment model could lower costs for joint replacements by nearly 16%. However, the profit margin based on the single bundled price for the providers was highly dependent on the complexity of the patient's health condition; a high-profit margin would exist only if the provider admitted a patient with fewer complications.

In 2013, a Bundled Payments for Care Improvement implementation [23] for total joint arthroplasty (Diagnosis-Related Group (DRG) 469 and 470) implemented by the New York

University Langone Medical Centre focused on restructuring processes related to preadmission and services offered during the inpatient stay. The single payment offered to the providers was set to cover services up to a 90-day period of providing medical services to a patient starting from the date of admission. This value-based payment structure resulted in savings of about 8.1% and 17% for DRG's 469 and 470 respectively, reductions in length of stay from 3.58 days to 2.96 days as well as a reduction in the rate of readmission (7% to 5% over a period of 30 days).

In 2013, Medicare's Bundled Payment for Care Improvement (BPCI) initiative developed by CMS [24] proposed four different bundled payment models to the providers for bundling of services as an episode of care and pricing them accordingly. Model 1 included bundling of services related to only inpatient care under which the providers are reimbursed using the payment rates defined under the Inpatient Prospective Payment System (IPPS). Model 2 includes bundling of services related to inpatient care, readmission, physician and post-acute care. Model 3 only includes bundling of services related to post-acute care. For Model 2 and Model 3, Medicare uses the FFS method to reimburse providers. The total expenditure is then compared against a single bundled price determined by CMS. If the total expenditure is less than the pre-determined single price, then the providers get to keep the difference. Model 4, includes bundling of services related to inpatient care, physicians, readmissions under which the CMS reimburses the providers with a single predetermined bundled price for an episode of care. The results of the BP implementation are mixed in part because providers are allowed to decide which parts of encounters should be reimbursed with BP and which ones are reimbursed via FFS.

Though the implementation of bundled payment looks promising, in most of the BP implementations, the characterization of an episode of care has been manual and does not consider comorbidities. Due to the heterogeneous nature of the patient's health condition, certain services might be included or excluded from the given episode of care. Because of the ambiguity associated with characterizing an episode of care, the reimbursement price for an episode of care can vary significantly. The variation in price for an episode of care involves a high level of risk for both payers and providers which discourages the adoption of bundled payments and make it difficult to reach an agreement on the single price for a given episode of care.

There have been several studies that assist in defining and characterizing an episode of care for a given primary diagnosis. For example, Mehta et al.[25] defines an episode of care for diabetic foot ulcers by analyzing the resource utilization level of the patients. An increase in utilization levels marks the beginning of an episode whereas a drop in the utilization levels to the baseline level marks the end of an episode of care. Schulman et al. [26] used the average weekly charges for patients suffering from migraine to determine the start and end dates for an episode of care. Alemi et al. [27] used the time interval and similarity between two consecutive diagnoses to determine the duration of an episode of care. However, the results of these methodologies are not generalizable since they do not assist in determining the actual length of an episode of care with any primary diagnosis.

Zhang et al. [12] proposed a cluster-based approach to characterize an episode of care by clustering encounters based on similarity of a set of medical services received for treating patients and shows that it can reduce the financial risk of overpayments and underpayments. Zhang et al.[12] uses spectral clustering to group encounters based on similar procedural pattern within an episode of care. Vectors of services are used to characterize each patient, by using 0 or 1 to indicate whether the service has been provided to the patient. The number of clusters generated for an episode of care is automatically determined by the algorithm given a tunable input parameter α [12]. The study shows that by using a single bundle price per cluster of encounters, it can reduce the financial risk of overpayments and underpayments. However, the study does not consider the effect of comorbidities in the definition of a given episode of care.

Singh [13] extends Zhang et al. [12] to consider comorbidities by analyzing the effect of clustering of encounters associated with diagnosis most likely to precede and follow a diagnosis of interest. Singh [13] uses a correlation coefficient and directionality analysis to determine encounters most likely to precede and to follow the given encounter of interest. Once the first clustering step is complete, the output of the clustering step is fused with non-procedural information and then used as an input of a second classification step where supervised learning methods are to generate more homogeneous clusters of services for given episodes of care. Compared to Zhang et al. [12], Singh's [13] clustering based approach shows that it can further reduce the risk of overpayments and underpayments.

In this study, we propose a three-step approach for systemically pricing cluster of encounters in a CBBP by aiming to lower the risks of underpayments and overpayments, increasing the affordability of critical services while maximizing the surplus of the payer.

3. Methodology

To answer the two research questions stated in the introduction, this study proposes a four-step approach as illustrated in Figure 1. In this study, we first use the clustering based bundled payment approach proposed by Singh [13] to generate clusters of encounters for given episodes of care. In the second step, we use the Analytic Hierarchy Process (AHP) to assign priorities (or criticality) to each episode and its clusters. Thirdly, we propose a two-stage linear programming model which uses the cluster assignments and the normalized AHP weights to determine the single price of clusters of encounters in an episode of care under the CBBP system. Fourthly, we calculate the risk of overpayments and affordability of critical clusters using the optimal reimbursement price (i.e. the proposed price) for each cluster and the results are compared then with those resulting from using the mean cluster cost as the CBBP reimbursement price. A detailed explanation for each of the three steps is given in section 3.1, 3.2 and 3.3.

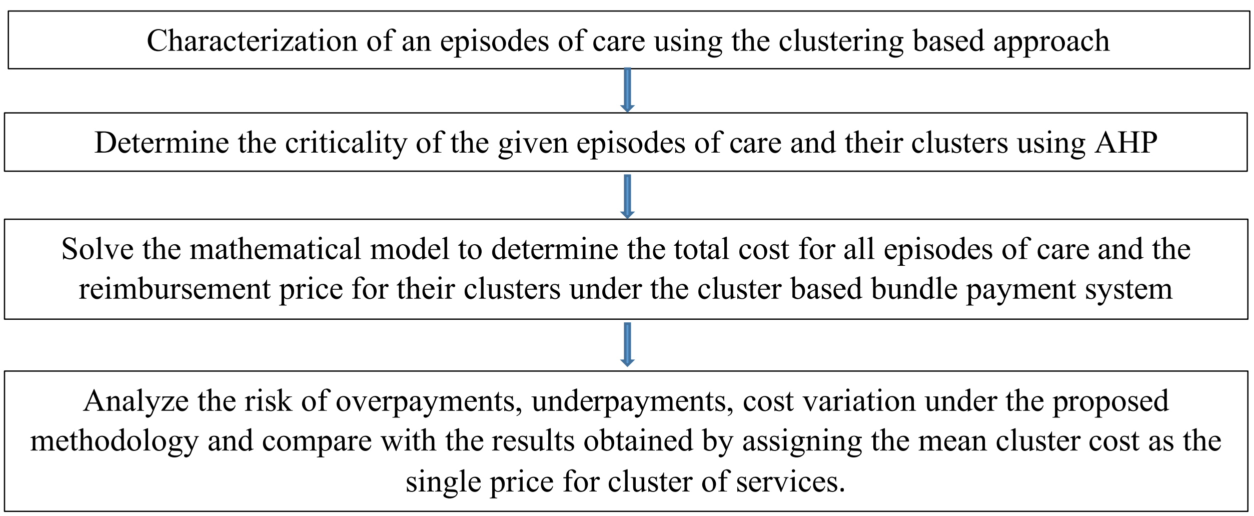

Figure 1: Overview of the propsoed methodology.

3.1 Characterizing an episode of care using the clustering based approach.

For clustering of encounters based on similar procedural pattern, we use the clustering based approaches proposed by Singh [13] where the value of the tuning parameter α is adjusted for each episode of care until the number of clusters generated is greater than three. The value of directionality is kept constant at 0.25 for each episode of care.

3.2 Determining criticality of an episode of care and their clusters using the Analytic Hierarchy Process.

After the episodes of care have been characterized using the CBBP approach, we use the Analytic Hierarchy Process (AHP) to first rank the three criteria's: the total number of encounters, the average overpayments and the average cost per encounter under the FFS System. We then use AHP weights to rank episodes of care in decreasing order of their criticality as a function of the three criteria's mentioned above. Then we use AHP again to rank the clusters of encounters for each episode of care in order of their criticality using the aforementioned criterion.

The first step in the AHP is to determine the relative weights (w_i), of the three criteria: (1) the total FFS cost, (2) the total amount of overpayments and (3) the total number of encounters used to rank the critical episodes of care and their cluster of encounters. For this, we construct the pairwise comparison matrix **A** = $[a_{ij}]$, where the value of the comparison a_{ij} is the ratio of $\frac{o_i}{o_j}$ i.e., the ratio of actual importance of criterion *i*, o_i, and criterion j, o_j, determined via Saaty's pairwise comparison scale [28]. Given that there are 6 possible combinations in which the criterions can be ordered, we see later in the section 5.2.1 that all of the priority orders have little to no impact on the number or the extent to which an episode of care is subsidized. Therefore, in this study we consider that $o_1 > o_2 > o_3$ resulting in a comparison matrix A.

$$\mathbf{A} = \begin{bmatrix} o_1/o_1 & o_1/o_2 & o_1/o_3 \\ o_2/o_1 & o_2/o_2 & o_2/o_3 \\ o_3/o_1 & o_3/o_2 & o_3/o_3 \end{bmatrix} \tag{1}$$

We obtain $\mathbf{AW} = \lambda\mathbf{W}$, where $\mathbf{W}$ is the normalized vector of priorities of each of the three criterions. An approximate method of determining the principal eigenvector **W** is to divide each element of the matrix A by the sum of its column and dividing each total by the number of elements in the row [28].

$$\mathbf{W} = [w_i] = \left[\frac{1}{n}\sum_{j=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right] \tag{2}$$

With the weighing of each criteria determined, we use the AHP to obtain the priorities for episodes of care with respect to each criteria i. We follow the same steps used in obtaining priorities of the three criterions shown in (1) and (2), however, we use the actual feature values for each episode of care with respect to criteria i to obtain the the pairwise comparison matrix $\mathbf{A_i}$ where the value of the comparison m_{xy}^{i} is the ratio of $\frac{f_x^i}{f_y^i}$, the actual performance of the episode of care $x \in E$ with respect to criteria i over the performance of episode $y \in E$ with respect to the same criteria i.

$$\mathbf{A_i} = \left[\frac{f_x^i}{f_y^i}\right] \tag{3}$$

Hence, $\mathbf{A_i}\mathbf{B_i} = \lambda_i\mathbf{B_i}$ where $\mathbf{B_i}$ is the vector of priorities of an episode of care $e \in E$ with respect to criteria i.

$$\mathbf{B} = [b_e^i] \tag{4}$$

The same steps are then repeated to obtain the priorities of clusters of encounters in an episode of care. Similar to (4), let $\mathbf{D_i}$ represent the vector of priorities of a cluster of encounters $c \in C_e$, in an episode of care $e \in E$.

$$\mathbf{D_i} = [d_{ec}^i] \tag{5}$$

After determining the relative priorities of each of the 3 criterion $[w_i]$,and the priorities of the episodes of care $e \in E$ $[b_e^i]$ and their clusters of encounters $c \in C_e$ $[d_{ec}^i]$ with respect to each criterion i, we calculate the overall priority of an episodes of care $e \in E, L_e$, and clusters of encounters $c \in C_e, K_{ec}$, is given by

$$L_e = \sum_{i=1}^{i=3} b_e^i . w_i \qquad \forall \ e \in E \tag{6}$$

$$K_{ec} = \sum_{i=1}^{i=3} d_{ec}^i . w_i \qquad \forall \ c \in C_e, \ e \in E \tag{7}$$

The output of the AHP is the priority of episodes of care and their clusters of encounters. This output in addition to extracted data for episodes of care and their clusters of encounters generated by using the clustering approach of Singh [13] is used as an input to the proposed mathematical model as explained in section 3.3.

3.3 Pricing of clusters of encounters in a CBBP system

In this section, we propose a two-stage linear programming model to determine the reimbursement price of clusters of services under the CBBP system. We first solve the mathematical model (Model 1) to re-allocate a total reimbursement across all episodes of care based on their criticality. We then solve a second mathematical optimization model (Model 2) to determine the reimbursement price for each cluster of encounters in the episode of care. Considering a worst-case scenario where the bundled payment system is not able to reduce the overall cost [15] (i.e. the total cost under the FFS system is equal to the total cost incurred under the bundled payment system), the proposed pricing mechanism aims to lower the risk associated with overpayment, underpayment, cost variation and the increase in the affordability of critical clusters of encounters. Therefore, even if implementation of our proposed methodology is no better than the FFS system in reducing overall costs, we may have an opportunity to facilitate the adoption of BP by lowering risks of overpayments and improved affordability under the BP system. We leave it to the providers to adopt the best set of practices for an episode based on the proposed single price under the CBBP system to lower the total cost for an episode.

3.3.1 Model 1: Allocating budget to an episode of care

In this section, we readjusted the total reimbursement cost across all encounters within the three episodes of care taking into consideration the criticality of each episode of care.

3.3.1.1 Sets

E Episodes of care

3.3.1.2 Parameters

φ_e Actual total cost of all encounters within an episode of care $e \in E$ under the FFS System

τ Actual total cost of all encounters under the FFS System across all episodes of care $e \in E$

L_e Priority of an episode of care $e \in E$

3.3.1.3 Decision Variables

X_e Total reimbursement amount to be used to reimburse all encounters of episode of care $e \in E$

k_e^u Percentage difference between the actual allocated and the maximum allowable reallocated budget for an episode of care $e \in E$

k_e^l Percentage difference between the actual allocated and the minimum allowable reallocated budget for an episode of care $e \in E$

3.3.1.4 Objective Function

$$Minimize \ \sum_{e \in E}(X_e L_e) \qquad (8)$$

The objective function (8) minimizes the product of the criticality of an episode of care $e \in E$ (L_e) and the allocated budget under the BP system (X_e). Minimizing the objective function ensures that the total readjusted reimbursement amount across all encounters within an episode $e \in E$ decreases with an increase in criticality for an episode of care.

3.3.1.5 Constraints

Constraint (9) ensures that the total cost under the fee for service system across all encounters should be equal to the total reimbursement cost across all encounters incurred under the bundled payment system.

$$\sum_{e \in E} X_e = \tau \qquad (9)$$

Constraint (10) ensures that the total cost for an episode of care $e \in E$ under BP system should not be greater than $(1 + k_e^u)$ % of the total cost (φ_e) incurred for episode $e \in E$ under FFS System.

$$X_e \leq (1 + k_e^u)\varphi_e \quad \forall\, e \in E \qquad (10)$$

Constraint (11) ensures that the total cost for an episode of care $e \in E$ under BP should not be less than $(1 - k_e^l)$ % of the total cost (φ_e) incurred for episode $e \in E$ under FFS System.

$$X_e \geq (1 - k_e^l).\varphi_e \quad \forall\, e \in E \qquad (11)$$

Constraint (12) provides the upper and lower bounds on the values of k_e^u, k_e^l .

$$0 \leq k_e^u, k_e^l \leq p\ \forall\, e \in E,\, c \in C_e \qquad \text{where } p \in (0,1) \qquad (12)$$

For any pair of episode of care $i \in E$ and $j \in E$, if $L_i \geq L_j$, constraint (13) and (14) ensure that the maximum reimbursement price for the most critical episode of care $i \in E$ is lower or equal than the maximum reimbursement for lesser critical episode of care $j \in E$.

$$k_i^u.\varphi_i \leq k_j^u.\varphi_j \qquad \forall\, i \in E, j \in E \mid L_i \geq L_j \qquad (13)$$

$$k_i^u.\varphi_i \geq k_j^u.\varphi_j \qquad \forall\, i \in E, j \in E \mid L_i < L_j \qquad (14)$$

Similarly, for any pair of episode of care $i \in E$ and $j \in E$, if $L_i \geq L_j$, constraint (15) and (16) ensure that the minimum reimbursement price for the most critical episode of care $i \in E$ is greater or equal than the minimum reimbursement for lesser critical episode of care $j \in E$.

$$k_i^l.\varphi_i \geq k_j^l.\varphi_j \qquad \forall\, i \in E, j \in E \mid L_i \geq L_j \qquad (15)$$

$$k_i^l.\varphi_i \leq k_j^l.\varphi_j \qquad \forall\, i \in E, j \in E, \mid L_i < L_j \qquad (16)$$

3.3.2 Model 2: Pricing clusters of encounters

In this model, we use the total reimbursement cost for an episode of care as determined from model 1 and allocate a single reimbursement price for all encounters in a cluster for an episode of care.

3.3.2.1 Sets

P_{ec} Encounters within a cluster of services $c \in C_e$ in an episode of care $e \in E$

3.3.2.2 Parameters

α_{ecp} Actual FFS cost of encounter $p \in P_{ec}$

K_{ec} Normalized relative weight for clusters of encounters $c \in C_e$ in an episode of care $e \in E$

ω_{ec} Mean FFS cost for encounters within cluster $c \in C_e$ within an episode of care $e \in E$

n_{ec} Total number of encounters in the cluster $c \in C_e$ of episode of care $e \in E$

Q_{ec} 3rd Quartile of the cost distribution of the encounters in cluster $c \in C_e$ of the episode of care $e \in E$.

3.3.2.3 Decision Variables

Y_{ec} Proposed reimbursement price for encounters in a cluster $c \in C_e$ of episode of care $e \in E$ under the CBBP

m_{ec}^{u} Percentage difference between the maximum allowable reimbursement price and the mean FFS cost for cluster $c \in C_e$ within an episode $e \in E$.

m_{ec}^{l} Percentage difference between the minimum allowable reimbursement price and the mean FFS cost for cluster $c \in C_e$ within an episode $e \in E$.

3.3.2.4 Objective Function

$$Minimize \sum_{e \in E} \sum_{c \in C_e} (Y_{ec} . K_{ec})$$

The objective function minimizes the product of criticality of cluster of encounter $c \in C_e$ and the proposed reimbursement price under the CBBP system.

3.3.2.5 Constraints

Constraint (17) ensures that the total cost of all encounters (Y_{ec}) within an episode of care $e \in E$ is equal to the total budget (X_e)allocated to an episode of care $e \in E$, obtained from model 1.

$$X_e = \sum_{c \in C_e} Y_{ec}.n_{ec} \quad \forall\, e \in E \tag{17}$$

Constraint (18) ensures that the reimbursement price (Y_{ec}) of a cluster of encounters $c \in C_e$ within an episode of care $e \in E$ should not be greater than $(1 + m^u_{ec})$% of the mean cost (ω_{ec}) for cluster $c \in C_e$ under FFS System.

$$Y_{ec} \leq (1 + m^u_{ec})\omega_{ec} \quad \forall\, e \in E,\, c \in C_e \tag{18}$$

For any pair of clusters $i \in C_e$ and $j \in C_e$ for the same episode $\in E$, if $K_{ei} \geq K_{ej}$ constraint (19) and (20) ensure that the maximum reimbursement price for the most critical cluster $i \in E$ is lower or equal than the maximum reimbursement for lesser critical cluster $j \in E$.

$$m^u_{ei}.\omega_{ei} \leq m^u_{ej}.\omega_{ej} \qquad \forall\, e \in E,\, i \in C_e, j \in C_e \;\; | \, K_{ei} \geq K_{ej} \tag{19}$$

$$m^u_{ei}.\omega_{ei} \geq m^u_{ej}.\omega_{ej} \qquad \forall\, e \in E,\, i \in C_e, j \in C_e \;\; | \, K_{ei} < K_{ej} \tag{20}$$

For any pair of clusters $i \in C_e$ and $j \in C_e$ for the same episode $\in E$, if $K_{ei} \geq K_{ej}$ constraint (21) and (22) ensure that the minimum reimbursement price for the most critical cluster $i \in E$ is lower or equal than the minimum reimbursement for lesser critical cluster $j \in E$.

$$m^l_{ei}.\omega_{ei} \geq m^l_{ej}.\omega_{ej} \qquad \forall\, e \in E, \forall\, e \in E,\, i \in C_e, j \in C_e | \, K_{ei} \geq K_{ej} \tag{21}$$

$$m^l_{ei}.\omega_{ei} \leq \; m^2_{ej}.\omega_{ej} \qquad \forall\, e \in E,\, i \in C_e, j \in C_e \, | \, K_{ei} < K_{ej} \tag{22}$$

Constraint (23) provides the upper and lower bounds on the values of k^u_e, k^l_e .

$$0 \leq m^u_{ec}, m^l_{ec} \;\leq p \;\forall\, e \in E,\, c \in C_e \quad \text{where } p \in (0, .2) \tag{23}$$

3.4 Metrics of Comparison

In this study we focus to reduce the reimbursement cost of critical clusters, making them more affordable for the payers and seeking to offer a more equitable healthcare system. Reducing the reimbursement price for a cluster of encounters will also result in reducing the number of overpaid encounters and the amount of overpayments while increasing the total amount of underpayments, number of underpaid encounters and the total surplus to the payers. Since we consider a worst-case scenario where the total cost of reimbursing all encounters under the proposed methodology is equal to the total cost of reimbursing encounters under the fee for service system, lowering the amount of overpayments or number of overpaid encounters for critical clusters of encounters will result in an increase in the reimbursement price on the number and hence an increase in the amount for overpaid encounters of less critical clusters. An increase in the reimbursement price or amount of overpayments can have a varied impact on the overall healthcare system depending on the criticality of each cluster of encounters. Therefore, we use the weighted sum of the total number of overpaid encounters, the total amount of overpayments and the change in the reimbursement price, and their criticality to highlight the significance of the clusters of encounters while computing the comparison metrics.

To understand the effect of re-adjusting the total budget for an episode of care and the reimbursement price of clusters of encounters on the affordability of healthcare services, we compare the results of our proposed two-stage mathematical model with the pricing of clusters using the mean cost per cluster over the following metrics of comparison:

a) Criticality adjusted total overpayments (CO): Overpayments reflect the excess amount reimbursed by the payer under the proposed model when compared to an encounter's FFS cost. The adjusted total overpayments (CO) corresponds to the weighted sum of the criticality and the total amount of overpayments across all clusters of encounters for an episode of care. A comparatively high value of this metric indicates a lower affordability of healthcare services.

$$CO = \sum_{e\in E} K_{ec} . \sum_{c\in C_e} \sum_{p\in P_{ec}} \left(Y_{ec} - \alpha_{ecp}\right) \mid Y_{ec} \geq \alpha_{ecp}$$

b) Criticality adjusted affordability for clusters of encounters (CA): This metric corresponds to the weighted difference between the optimal reimbursement price for a cluster of encounters under the proposed model and the mean cost of the cluster of encounters under FFS. A positive value of this metric indicates the proposed model increases the affordability of healthcare services.

$$CA = \sum_{e \in E} \sum_{c \in C_e} (\omega_{ec} - Y_{ec}).K_{ec}$$

4. Data

The data repository used in this study comprises of HIPPA compliant insurance claims records of 1.6 million residents for years 2007 to 2013. From the repository we select the 153 most expensive episodes of care for the year 2007 across all providers in the Greater Rochester area. We then characterize these episodes of care using Singh's [13] clustering based approach which results in 704 clusters of encountersand 30,271 claims records. Table 1 shows an overview of the dataset in which the episodes of care, based on their ICD – 9 codes are grouped into 13 different categories.

Table 1: Summary of the dataset

Category	Current Budget	Number of Encounters	Number of Episodes	Average Cost per encounter
Circulatory System	$69,750,767	5,574	28	$12,514
Digestive System	$45,697,466	4,545	20	$10,054
Genitourinary System	$20,573,938	2,369	12	$8,685
Ill-defined Conditions	$19,246,781	2,351	8	$8,187
Immunity Disorders	$7,141,879	687	6	$10,396
Injury	$8,614,013	781	5	$11,029
Poisining	$30,188,667	2,307	13	$13,086
Mental Disorders	$408,094	56	1	$7,287
Musculoskeletal System	$28,812,079	1,611	10	$17,885
Neoplasms	$37,181,661	2,881	26	$12,906
Pregnancy	$41,234,094	5,288	16	$7,798
Respiratory System	$17,372,520	1,641	6	$10,587

Skin and Subcutaneous Tissue	$1,438,317	180	2	$7,991

The current budget represents the cost for reimbursing all encounters for all episodes of care under the given category. The total reimbursement cost for all encounters across the 13 categories is $327,660,276. As per the data used for this study, episodes of care related to Circulatory disorders constitute the highest propotion of the total budget (21.3 %), highest number of episodes of care (18.3 %) and the most number of encounters (18.4 %). Episodes of care related to Musculoskelatal disorders have the highest average cost per encounter ($17,885) among all the given categories.

5. Results

5.1 Characterization of an episode of care using Singh's [13] clustering based approach

In this section, we show the results of characterizing an episode of car using Singh's extended CBBP approach as shown in Figure 2 to Figure 7. The figures provide a categorical breakdown of the results showing the episodes of care (related to each category) with primary diagnosis codes, the mean cluster cost, cluster ID (or number of clusters generated for a given episode) and average amount overpayments (calculated using the Mean FFS cost) for each cluster of encounters.

Avg Overpayments: $191.99 – 7K

	Cluster ID							
Episode..	1	2	3	4	5	6	7	8
4019	$6,776.24	$7,557.51	$9,027.61	$7,646.15	$6,610.46	$7,010.29		
4148	$21,672.80	$10,436.10	$8,939.04	$27,100.70				
4240	$25,822.70	$9,603.12	$20,816.40	$24,207.10				
4241	$29,990.70	$41,567.50	$38,260.60	$8,849.31	$7,774.77	$7,920.05	$14,934.60	$29,258.70
4260	$14,902.90	$12,225.60	$13,289.80	$13,022.40				
4270	$7,951.56	$8,426.14	$8,917.58	$13,991.00				
4271	$14,828.00	$19,564.50	$7,800.66	$7,835.82	$12,192.00			
4359	$8,190.47	$8,062.23	$7,976.77	$7,972.52	$8,908.70			
4414	$25,352.10	$22,003.40	$7,761.62	$15,333.40	$20,985.80	$36,012.90		
4580	$9,912.71	$7,839.86	$7,192.45	$7,094.10	$7,126.79			
4589	$7,690.15	$11,980.60	$11,289.50					
40391	$9,124.44	$11,425.60	$9,440.83	$16,375.80				
41011	$14,431.50	$16,771.40	$8,848.37	$16,022.20	$13,793.40	$29,362.80	$19,992.50	
41402	$13,767.30	$11,613.60	$12,203.50					
41519	$8,642.88	$8,145.57	$8,888.38	$12,712.70	$18,439.30	$13,832.20		
42613	$15,291.60	$11,548.30	$11,482.30					
42732	$10,329.60	$11,185.00	$7,145.25	$8,388.27	$7,838.66	$13,861.40		
42741	$10,108.50	$15,843.30	$25,527.40					
42781	$12,465.40	$13,833.70	$13,705.00	$13,966.80	$15,939.10			
42789	$14,071.00	$12,926.40	$8,553.16	$9,880.71	$6,842.70	$11,250.30	$7,329.15	$6,721.38
42831	$8,565.68	$8,519.33	$9,270.48					
43310	$10,690.40	$10,874.40	$8,107.86	$11,820.20	$9,455.18	$21,034.60	$12,521.90	
43411	$11,011.30	$10,816.10	$10,151.90	$9,954.89	$11,993.70	$9,196.88		
43491	$9,101.43	$8,302.48	$9,507.50	$9,318.40	$10,420.50			
44021	$15,502.60	$15,505.80	$21,058.60	$16,210.60	$19,659.60			
44024	$20,431.10	$17,384.10	$20,113.10					
44422	$18,930.70	$21,921.60	$19,577.90	$8,381.04				
45341	$10,972.20	$14,063.10	$7,625.50	$11,432.00	$7,881.35	$10,628.50	$10,061.20	

Figure 2: Mean FFS Cost broken down by Cluster ID vs. Episode(ICD -09 code) related to Circulatory disorders.

Episode..	Cluster ID 1	2	3	4	5	6	7	8	9
5362	$7,383.77	$7,871.40	$6,755.54						
5400	$9,115.18	$12,388.00	$11,239.40	$9,919.59	$10,203.20	$9,776.36			
5409	$8,338.93	$8,208.93	$8,386.19	$8,536.13	$8,138.63	$8,528.60	$7,801.49	$8,066.69	
5550	$6,941.09	$17,828.60	$7,319.42						
5570	$16,826.60	$8,407.85	$13,012.90						
5589	$6,902.31	$6,999.30	$6,932.24	$6,399.37	$6,886.96	$7,065.90	$8,545.92	$8,686.22	$14,731.20
5609	$11,646.70	$9,379.83	$7,658.14	$11,336.10	$8,080.41	$8,286.29			
5770	$13,575.80	$10,306.20	$19,174.10	$10,466.40	$14,411.80	$13,286.60	$8,662.26	$7,559.70	
5781	$9,643.27	$9,099.49	$9,001.17						
5789	$9,009.98	$9,246.63	$10,109.30	$10,097.30	$12,007.00	$7,719.24			
53081	$11,922.30	$13,885.30	$7,345.41	$7,595.02					
55221	$11,588.10	$10,580.50	$11,877.40	$17,135.80					
55321	$14,679.20	$11,434.40	$11,212.40						
56081	$15,680.50	$7,503.86	$12,636.00	$8,320.26	$17,568.70	$8,134.92	$8,976.52		
56089	$18,533.80	$8,750.54	$8,074.43						
56210	$13,950.30	$16,113.20	$7,349.98						
56211	$7,638.53	$18,584.60	$7,655.95	$16,358.80					
56969	$20,712.20	$14,318.00	$8,903.93						
57400	$10,665.10	$11,161.90	$12,303.20	$16,126.40	$14,456.40	$10,580.40			
57410	$10,723.70	$8,017.58	$17,059.40	$8,214.19	$11,378.00				

Avg Overpayments: $324.67 – 6K

Figure 3: Mean FFS Cost broken down by Cluster ID vs. Episode(ICD -09 code) related to Digestive system disorders.

Episode..	Cluster ID 1	2	3	4	5
7210	$22,584.30	$16,658.00	$28,591.50		
7211	$22,788.00	$32,021.50	$20,911.90		
7213	$7,865.14	$7,904.55	$19,004.70	$20,802.10	
7220	$23,420.00	$21,243.50	$26,848.40	$14,654.90	
7242	$8,210.24	$8,264.12	$7,274.62		
7384	$30,162.90	$28,222.40	$15,585.50	$25,010.20	
72210	$8,474.57	$10,641.10	$14,194.80	$15,650.70	$16,386.90
72252	$25,848.50	$36,054.20	$8,461.57	$7,375.78	$25,228.00
72402	$11,830.10	$12,847.40	$8,468.71	$20,649.70	$19,447.60
73313	$8,267.90	$9,157.05	$10,919.60	$13,123.30	$15,172.90

Avg Overpayments: $336.71 – 8K

Figure 4: Mean FFS Cost broken down by Cluster ID vs. Episode(ICD -09 code) related to Musculoskelatal disorders.

Episode..	Cluster ID 1	2	3	4	5	6	7	8	9
5849	$7,767.27	$7,621.39	$6,848.16	$7,403.56	$7,553.73	$7,785.88	$7,824.86	$8,714.86	$8,075.91
5920	$6,596.69	$9,865.32	$8,088.72	$5,818.62	$11,087.60				
5921	$6,766.79	$9,525.72	$8,677.81						
5990	$8,625.71	$7,442.54	$13,330.40	$11,988.80	$7,358.08	$8,537.02	$8,561.71		
6170	$9,194.82	$8,693.80	$8,782.52						
6183	$9,543.02	$11,322.10	$10,167.60	$10,132.60	$8,763.39	$9,083.32			
6202	$11,232.50	$8,413.51	$8,739.16						
6256	$8,246.55	$8,124.74	$10,408.60	$7,812.46					
6262	$8,600.09	$8,571.70	$9,150.28	$9,722.96	$8,740.04				
59010	$6,353.04	$6,380.01	$7,671.25	$6,646.71	$7,649.36	$8,127.17			
59080	$9,786.81	$7,863.49	$6,750.56	$6,681.71	$16,424.30	$6,215.77			
60001	$7,628.08	$10,903.90	$8,854.17						

Avg Overpayments: $126.27 – 5K

Figure 5: Mean FFS Cost broken down by Cluster ID vs. Episode(ICD -09 code) related to Genitourinary disorders.

Episode..	Cluster ID 1	2	3	4	5	6	7	8
185	$14,760.90	$14,742.70	$14,288.60	$13,885.20	$14,554.90	$14,519.30	$15,513.50	$14,994.40
220	$8,756.09	$8,304.14	$8,622.15	$8,580.84				
430	$10,323.10	$22,110.20	$34,395.80	$23,270.20				
431	$9,589.08	$7,965.67	$10,318.50	$13,367.90				
515	$14,063.30	$8,987.51	$11,032.10					
566	$8,432.47	$22,520.10	$8,715.47					
1533	$9,746.87	$16,898.40	$17,005.60	$15,519.90				
1534	$17,701.50	$8,779.72	$15,166.20					
1536	$14,907.20	$19,304.90	$18,530.10	$11,189.10				
1540	$20,582.10	$10,166.50	$16,993.90					
1541	$15,340.80	$14,111.60	$18,416.70	$17,143.10				
1623	$9,147.20	$11,124.30	$11,934.40	$18,856.80				
1625	$14,024.20	$7,862.66	$18,442.30					
1744	$11,773.40	$10,890.80	$15,835.10					
1748	$13,116.90	$15,511.10	$13,018.90					
1820	$10,783.80	$11,648.70	$14,827.90	$9,946.05	$10,337.60	$11,694.30	$10,546.80	
1890	$15,470.20	$16,094.10	$10,111.10	$11,624.50	$8,076.04			
1972	$10,872.40	$10,570.70	$13,027.40	$12,448.90	$8,447.06	$7,887.37		
1977	$8,489.91	$8,611.21	$17,797.00	$9,225.14				
1983	$10,972.60	$12,284.00	$9,080.14	$15,672.80				
1985	$16,023.50	$9,816.14	$10,297.00					
2113	$7,746.53	$7,285.86	$16,116.20	$14,172.00				
2180	$9,244.82	$8,728.59	$9,264.82					
2181	$8,750.78	$9,311.33	$8,432.32	$8,996.59				
2189	$9,192.65	$9,109.32	$8,967.95					
2252	$8,254.11	$10,544.80	$22,911.60	$23,658.10				

Avg Overpayments: $185.75 – 10K

Figure 5: Mean FFS Cost broken down by Cluster ID vs. Episode(ICD -09 code) related to Neoplasmic disorders

Episode..	Cluster ID 1	2	3	4	5	6	7	8	9
64231	$7,345.85	$10,275.30	$6,877.98						
64241	$8,998.86	$7,142.22	$7,062.57	$7,561.09					
64251	$7,639.12	$7,371.16	$9,134.22						
64421	$6,794.41	$8,937.55	$7,098.07	$5,207.54	$4,397.86	$6,359.56	$6,579.00		
64511	$6,920.92	$6,761.29	$8,465.99						
64891	$7,094.75	$6,366.65	$6,901.83	$6,412.07	$6,450.43	$6,840.88	$6,949.52	$8,907.76	
64893	$5,934.26	$5,266.93	$5,395.12	$9,606.53	$5,187.31				
65221	$9,145.08	$11,354.40	$9,726.15	$9,435.19	$8,979.47				
65421	$9,620.37	$6,682.78	$6,476.07	$9,073.85	$8,938.02	$9,730.10	$8,695.72	$9,529.27	$9,390.27
65661	$9,363.08	$7,192.45	$6,719.37	$7,063.02	$7,183.48				
65801	$9,315.99	$7,426.00	$7,061.72						
65811	$7,106.47	$8,994.76	$6,738.28						
65971	$6,969.69	$6,431.22	$7,246.87	$6,874.36	$8,801.21				
65981	$6,997.23	$6,898.47	$8,659.77						
66331	$6,551.96	$6,867.14	$6,540.08	$7,304.48	$6,402.35				
66551	$6,474.76	$6,739.80	$6,852.75						

Avg Overpayments: $167.86 – 1K

Figure 6: Mean FFS Cost broken down by Cluster ID vs. Episode(ICD -09 code) related to Pregnancy.

Episode..	Cluster ID 1	2	3	4	5	6	7
2761	$6,975.57	$6,814.94	$7,255.60	$9,737.94	$9,054.33		
4660	$5,943.47	$6,928.39	$9,465.01	$9,749.79	$7,128.18	$8,856.84	
5070	$9,452.47	$16,142.30	$9,187.45	$10,831.00			
6822	$7,946.68	$9,403.01	$11,433.80	$6,750.60			
6827	$6,837.23	$10,241.20	$7,934.25	$8,139.48			
25012	$6,750.54	$7,053.30	$7,971.27	$7,636.18			
25060	$8,768.25	$7,391.81	$14,038.70	$15,176.60			
25070	$15,782.10	$20,107.10	$18,468.00				
25080	$16,127.00	$15,200.50	$16,189.50	$10,699.70	$8,059.97	$7,399.56	$7,870.15
25082	$13,343.00	$8,565.44	$9,775.89				
49122	$8,207.83	$6,987.00	$12,042.80	$7,764.02	$6,718.90	$6,694.78	
49322	$8,661.07	$8,144.50	$7,647.55	$7,663.93			
51881	$14,801.10	$10,519.00	$9,278.82	$20,975.80	$8,214.58	$11,796.60	$13,844.80
51884	$13,417.50	$10,547.80	$15,586.80				
V552	$17,460.20	$14,218.90	$13,224.90				
V553	$17,038.30	$15,783.40	$13,096.00				
V5331	$12,844.10	$13,273.50	$17,240.00				
V5332	$27,026.40	$21,136.80	$9,596.75				
V5811	$6,520.03	$7,287.01	$7,546.34	$7,265.40	$13,515.50	$17,407.60	$8,293.13

Avg Overpayments: $339.70 – 9K

Figure 7: Mean FFS Cost broken down by Cluster ID vs. Episode(ICD -09 code) related to Immunity , Injury, Respiratory and Skin disorders

	Cluster ID								
Episode..	1	2	3	4	5	6	7	8	9
7802	$8,454.23	$7,766.45	$7,460.78	$7,237.33	$10,778.20	$7,850.56	$8,120.11	$7,664.04	$8,678.58
7804	$7,451.21	$8,240.27	$8,111.50	$7,124.56	$8,046.02				
7806	$9,633.67	$7,983.38	$12,853.40	$8,016.44	$5,898.51				
7999	$7,994.97	$8,187.78	$6,172.61	$5,781.04					
8082	$16,437.40	$7,583.62	$9,180.67	$7,573.03	$8,794.62	$8,403.95			
9974	$8,609.70	$8,822.64	$22,268.30	$13,962.90					
29281	$5,981.84	$7,224.76	$7,738.81	$6,639.93	$7,885.06				
78039	$9,003.51	$9,224.93	$8,462.80	$8,372.65	$10,026.80	$4,942.34	$6,805.73	$8,041.24	
78097	$10,042.30	$8,420.36	$9,794.26						
78659	$8,107.88	$7,459.65	$6,549.11	$7,872.31	$6,749.64	$7,326.13	$8,724.29	$7,472.60	$8,276.82
78791	$7,736.12	$7,101.94	$9,275.41	$12,578.00					
82009	$15,136.20	$15,112.10	$15,722.60	$6,447.33	$14,546.30	$13,937.60			
82021	$14,736.30	$15,243.50	$15,298.20	$12,084.60	$17,137.00	$12,083.40	$12,923.70		
99601	$14,766.60	$16,592.00	$15,739.70						
99642	$15,716.90	$14,388.00	$9,544.95						
99661	$16,442.20	$23,448.90	$9,148.83						
99662	$10,153.00	$16,565.60	$11,945.50	$13,318.00	$19,609.00	$8,147.34	$13,418.60		
99672	$13,555.80	$7,847.42	$13,732.40						
99674	$19,840.90	$16,254.30	$10,069.80	$8,221.27	$17,012.30				
99811	$8,179.47	$7,346.57	$8,624.97	$10,081.70					
99812	$8,328.47	$8,122.78	$14,049.30	$12,431.00					
99859	$15,011.80	$10,807.70	$12,298.00	$7,714.77					

Avg Overpayments
$275.50 6K

Figure 8: Mean FFS Cost broken down by Cluster ID vs. Episode(ICD -09 code) related to Mental, Injury and Posining, and Ill defined disorders

5.2 Ranking episodes of care and clusters of encounters using AHP.

The following section shows the results of using AHP to identify and rank episodes of care and their clusters of encounters based on the three criterions: a) Average FFS cost per encounter (C_1), b) Average Overpayments (C_2) and c) the total number of encounters (C_3). Using AHP, we first rank the three criterions, then the episodes of care and finally the clusters of encounters.

5.2.1 Ranking of the three criterions

To construct the pairwise comparison matrix A, we first determine the absolute importance of criteria i using Saaty's pairwise comparison scale [29]. In our study, we assime that criteria C_1 i.e. Average FFS cost per encounter has the highest initial importance since this feature of an episode of care and clusters of encounters gives a better indication of which episodes of care or clusters of encounters are more critical. Since there are 2 possible ways to prioritize the remaining two criteria's, we test for the two combination and then decide on the best priority order.

Table 2: Effect of changing the priority order on number of subsidized episodes

C1	C2	C3	Number of Subsidized Episodes
1	2	3	76
1	3	2	76

As seen from Table 2, priority order for criteria 2 and criteria 3 has no impact on the number of episodes subsidized and the list of subsidized episodes of care remains unchanged in both the orders and therefore, we choose the priority order of $o_1 > o_2 > o_3$ for our study.

The individual importance of the three criterions are assumed to be $o_1 = 5, o_2 = 3, o_3 = 1$[1]. Using matrices shown in (1) and (2), we determine the normalized vector of priorities **W** shown in Table 3.

Table 3: Results of using AHP for ranking the three criterions.

	Pairwise Comparison Matrix A			Priority Vector $(\mathbf{W_i})$	Rank
	$\boldsymbol{C_1}$	$\boldsymbol{C_2}$	$\boldsymbol{C_3}$		
$\boldsymbol{C_1}$	1.00	1.67	5.00	0.63	1
$\boldsymbol{C_2}$	0.60	1.00	3.00	0.26	2
$\boldsymbol{C_3}$	0.20	0.33	1.00	0.11	3

The results of the priority matrix $(\mathbf{W_i})$ in Table 3 shows that the most important criteria are the total FFS cost followed by the average overpayments and the total number of encounters.

1 The rationale behind choosing weights in that particular order is stated in section 3.2 on Page 11 and Page 25.

5.2.2 Ranking episodes of care

Once we obtain the priority matrix ($\mathbf{W_i}$) for the 3 criterions, using (4) we then determine the priorities of each of the episodes of care with respect to the three criterions (C_1, C_2 and C_3). The results are depicted in Figure 9: Priority of episodes of care with respect to the three criteria's

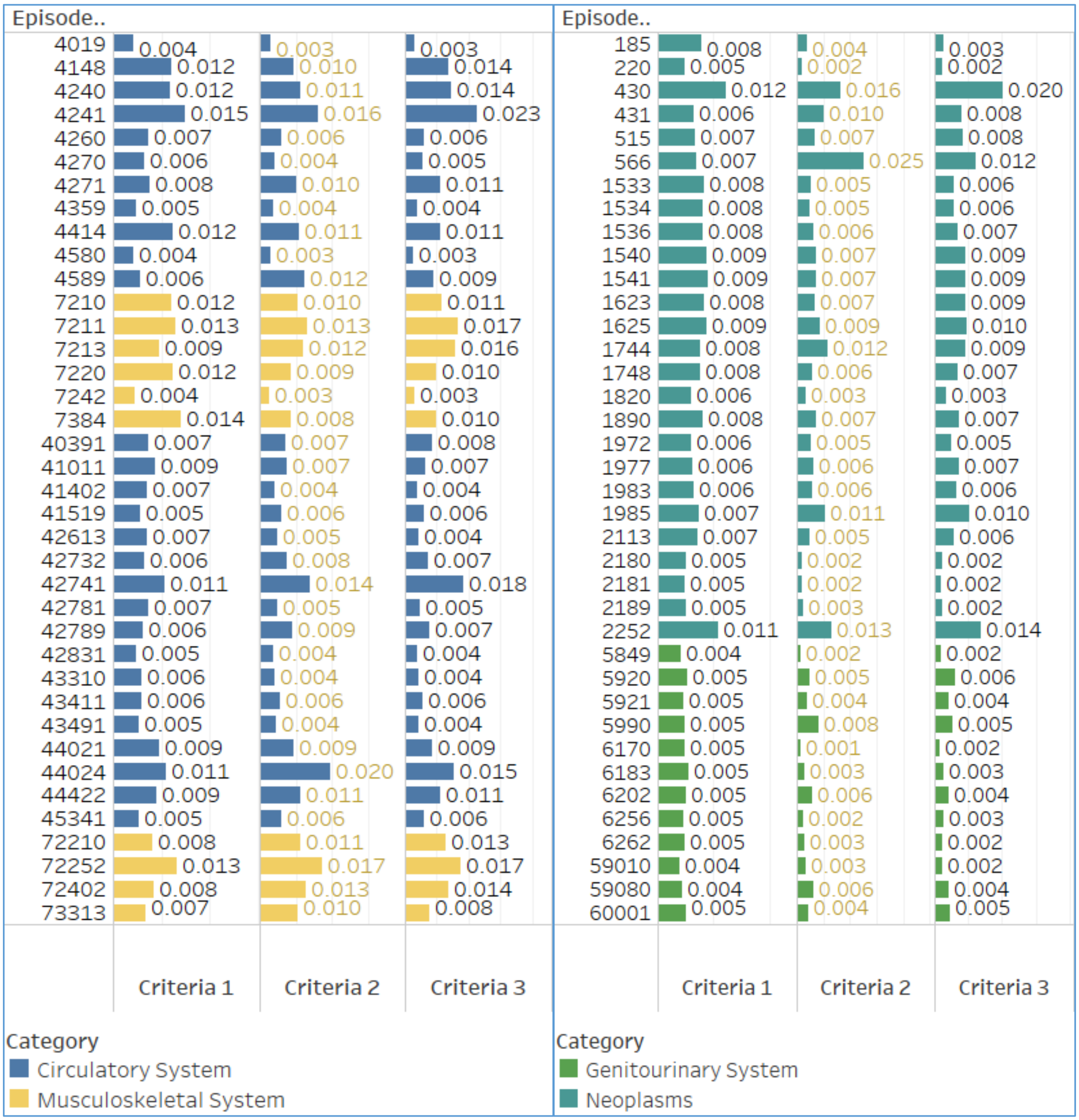

Figure 9: Priority of episodes of care with respect to the three criteria's

Figure 10: Priority of episodes of care with respect to the three criteria'sFigure 9 and Figure 10: Priority of episodes of care with respect to the three criteria's.

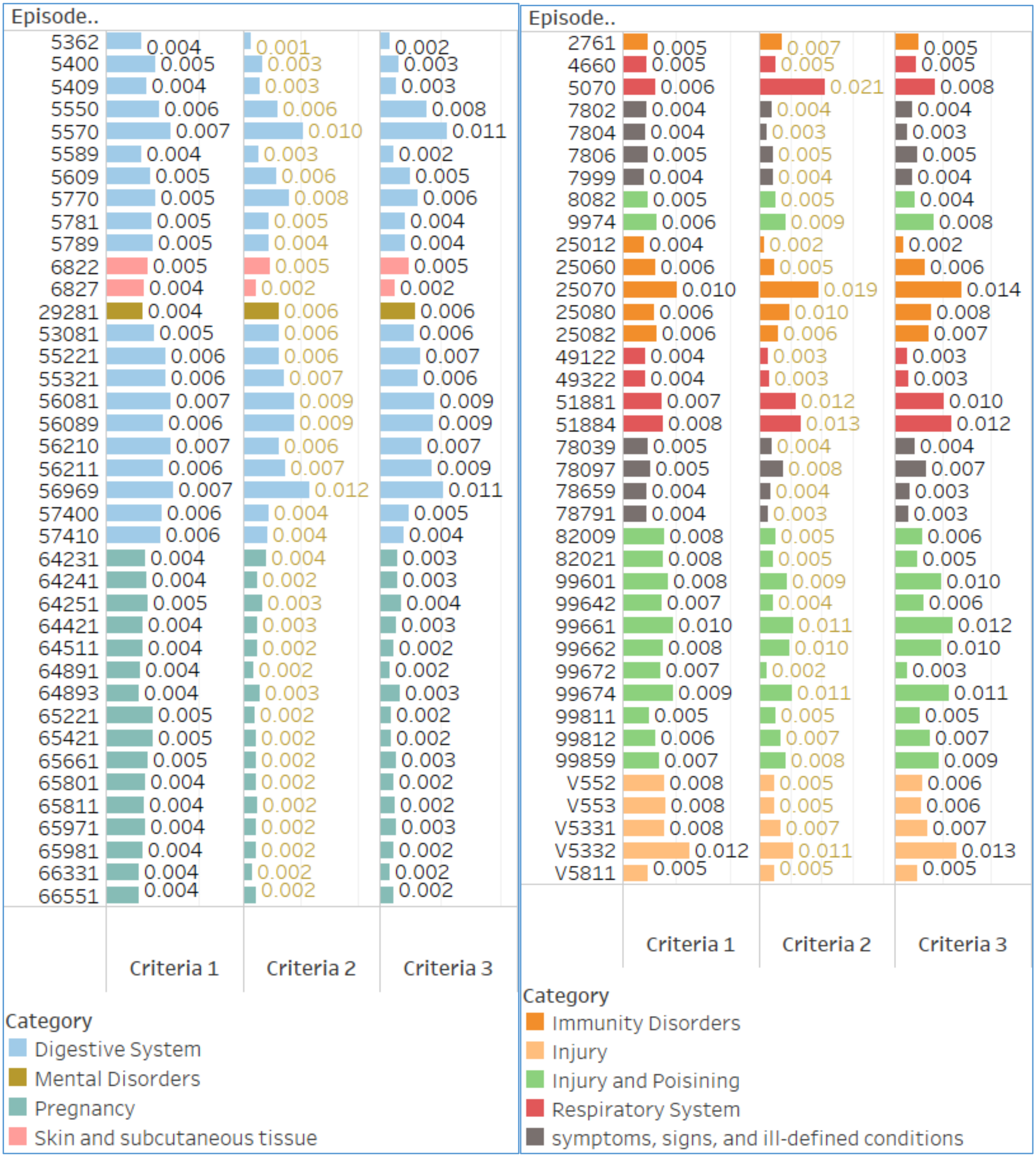

Figure 12: Priority of episodes of care with respect to the three criteria's

Using (5) and (6) we determine the priorities of episodes of care across all categories as shown in Table 4. From Table 4, we can see that the most critical episode of care (only valid for the data considered under this study) is the Aortic valve disorders with ICD-09 code 4241, which falls under disorders related to the circulatory system whereas the least critical episode of care i.e. ICD-09 code 66331 which falls under Pregnancy. This means that majority of the complications related to pregnancy have a comparatively low average cost and low risk of overpayments under the base model.

Table 4: Priorities of Episodes of Care

Rank	Episode	Weight	Rank	Episode	Weight	Rank	Episode	Weight	Rank	Episode	Weight
1	4241	0.0175	39	56081	0.0079	77	4270	0.0058	115	64251	0.0041
2	430	0.0153	40	99859	0.0078	78	42613	0.0058	116	7999	0.0040
3	72252	0.0150	41	40391	0.0076	79	43411	0.0058	117	78659	0.0039
4	7211	0.0143	42	1890	0.0076	80	45341	0.0057	118	2189	0.0038
5	42741	0.0136	43	1536	0.0075	81	185	0.0057	119	64231	0.0038
6	44024	0.0132	44	4589	0.0075	82	41402	0.0057	120	6262	0.0038
7	4240	0.0126	45	73313	0.0075	83	41519	0.0056	121	78791	0.0038
8	V5332	0.0125	46	V5331	0.0075	84	1972	0.0055	122	2180	0.0038
9	25070	0.0124	47	431	0.0074	85	57400	0.0055	123	64241	0.0038
10	4148	0.0123	48	56089	0.0073	86	5920	0.0055	124	65421	0.0037
11	2252	0.0120	49	9974	0.0073	87	53081	0.0054	125	6256	0.0037
12	7384	0.0119	50	515	0.0072	88	5990	0.0053	126	49322	0.0037
13	7213	0.0119	51	1748	0.0071	89	2761	0.0052	127	65661	0.0037
14	4414	0.0117	52	56211	0.0071	90	43310	0.0051	128	5409	0.0037
15	7210	0.0116	53	1533	0.0070	91	99811	0.0051	129	7242	0.0036
16	7220	0.0110	54	56210	0.0069	92	57410	0.0051	130	65221	0.0036
17	566	0.0108	55	1534	0.0069	93	99672	0.0051	131	4019	0.0036
18	99661	0.0106	56	25080	0.0069	94	5609	0.0050	132	220	0.0036
19	72402	0.0105	57	V553	0.0069	95	43491	0.0049	133	49122	0.0036
20	99674	0.0102	58	42789	0.0069	96	29281	0.0049	134	65971	0.0036
21	72210	0.0100	59	82009	0.0068	97	60001	0.0049	135	7804	0.0035
22	44422	0.0099	60	42732	0.0068	98	6202	0.0048	136	2181	0.0035
23	51884	0.0097	61	V552	0.0068	99	1820	0.0048	137	4580	0.0035
24	44021	0.0091	62	4260	0.0068	100	V5811	0.0047	138	64893	0.0034
25	4271	0.0091	63	1977	0.0066	101	5789	0.0047	139	65801	0.0034
26	1625	0.0091	64	25082	0.0066	102	5781	0.0047	140	6170	0.0034
27	99601	0.0089	65	99812	0.0066	103	6822	0.0047	141	64421	0.0034
28	56969	0.0088	66	99642	0.0066	104	7806	0.0047	142	6827	0.0034
29	1540	0.0088	67	55321	0.0065	105	8082	0.0047	143	65811	0.0033

30	5570	0.0088	68	55221	0.0065	106	4660	0.0046	144	59010	0.0033
31	51881	0.0088	69	5550	0.0064	107	78039	0.0045	145	65981	0.0033
32	1541	0.0088	70	2113	0.0064	108	59080	0.0045	146	64511	0.0033
33	1985	0.0087	71	82021	0.0063	109	5400	0.0044	147	5589	0.0032
34	1744	0.0086	72	1983	0.0063	110	5921	0.0044	148	5849	0.0031
35	99662	0.0086	73	42781	0.0061	111	42831	0.0044	149	66551	0.0031
36	5070	0.0086	74	25060	0.0061	112	4359	0.0043	150	25012	0.0030
37	1623	0.0085	75	78097	0.0060	113	6183	0.0042	151	5362	0.0028
38	41011	0.0079	76	5770	0.0060	114	7802	0.0042	152	64891	0.0028
									153	66331	0.0027

5.2.3 Ranking Categories of episodes of care

Using the results obtained in section 5.2.2, we aggregate the weights for episodes of care to calculate the priority of each of the 13 categories as shown in Table 5. Aggregating the weights of episodes of care is a reasonable approximation to determine which categories of encounters are highly critical in terms of the average cost, amount of overpayments and number of incidents.

Table 5: Priority order of categories

Categories	Priority Order
Musculoskeletal System	1
Circulatory System	2
Injury	3
Neoplasms	4
Poisining	5
Immunity disorders	6
Respiratory System	7
Digestive System	8
Mental Disorders	9
Ill defined Conditions	10
Genitourinary System	11
Skin and Subcutaneous tissue	12
Pregnancy	13

5.2.4 Ranking clusters of encounters

In this section, we show the priorities of clusters of encounters within an episode of care with respect to each criterion calculated using (5), (6), (7) as shown in Figure 11 and Figure 12.

	Cluster							
	1	2	3	4	5	6	7	8
29281	0.17	0.23	0.20	0.16	0.24			
4019	0.16	0.13	0.25	0.20	0.11	0.15		
40391	0.17	0.27	0.17	0.39				
41011	0.11	0.12	0.06	0.10	0.09	0.31	0.21	
41402	0.25	0.41	0.33					
4148	0.38	0.16	0.13	0.33				
41519	0.11	0.10	0.12	0.17	0.27	0.23		
4240	0.33	0.11	0.21	0.36				
4241	0.18	0.18	0.21	0.05	0.04	0.04	0.12	0.18
4260	0.26	0.23	0.23	0.28				
42613	0.42	0.33	0.25					
4270	0.20	0.29	0.22	0.29				
4271	0.24	0.32	0.09	0.11	0.23			
42732	0.20	0.28	0.09	0.12	0.11	0.18		
42741	0.16	0.34	0.50					
42781	0.20	0.17	0.18	0.15	0.30			
42789	0.13	0.25	0.11	0.15	0.07	0.15	0.07	0.06
42831	0.31	0.29	0.39					
43310	0.10	0.11	0.09	0.16	0.11	0.29	0.13	
43411	0.21	0.17	0.19	0.17	0.17	0.09		
43491	0.21	0.16	0.19	0.18	0.26			
4359	0.19	0.19	0.18	0.18	0.26			
44021	0.14	0.15	0.30	0.17	0.24			
44024	0.37	0.24	0.40					
4414	0.18	0.16	0.05	0.14	0.15	0.32		
44422	0.28	0.29	0.34	0.10				
45341	0.18	0.20	0.07	0.17	0.07	0.16	0.14	
4580	0.35	0.18	0.17	0.14	0.17			
4589	0.17	0.46	0.37					
7210	0.29	0.34	0.37					
7211	0.31	0.40	0.29					
7213	0.09	0.11	0.41	0.38				
7220	0.24	0.25	0.28	0.23				
72210	0.10	0.12	0.23	0.26	0.29			
72252	0.26	0.39	0.07	0.05	0.22			
72402	0.15	0.16	0.09	0.33	0.27			
7242	0.35	0.36	0.29					
73313	0.12	0.15	0.20	0.21	0.32			
7384	0.29	0.30	0.19	0.22				

Category
- Circulatory System
- Mental Disorders
- Musculoskeletal System

	Cluster								
	1	2	3	4	5	6	7	8	9
25012	0.22	0.21	0.30	0.27					
25060	0.20	0.14	0.30	0.35					
25070	0.25	0.50	0.25						
25080	0.22	0.17	0.16	0.19	0.09	0.08	0.09		
25082	0.42	0.26	0.32						
2761	0.15	0.13	0.14	0.33	0.25				
53081	0.23	0.42	0.17	0.18					
5362	0.35	0.38	0.27						
5400	0.13	0.24	0.19	0.13	0.17	0.13			
5409	0.14	0.11	0.10	0.13	0.11	0.14	0.13	0.13	
55221	0.21	0.22	0.22	0.36					
55321	0.47	0.26	0.27						
5550	0.18	0.61	0.21						
5570	0.51	0.16	0.33						
5589	0.08	0.09	0.07	0.07	0.09	0.09	0.12	0.11	0.27
56081	0.21	0.08	0.19	0.10	0.24	0.09	0.10		
56089	0.58	0.22	0.20						
5609	0.22	0.16	0.10	0.25	0.12	0.14			
56210	0.29	0.53	0.18						
56211	0.14	0.43	0.13	0.29					
56969	0.52	0.29	0.18						
57400	0.13	0.14	0.15	0.26	0.18	0.15			
57410	0.16	0.13	0.42	0.12	0.16				
5770	0.14	0.09	0.24	0.08	0.15	0.16	0.07	0.06	
5781	0.34	0.30	0.36						
5789	0.15	0.17	0.16	0.18	0.24	0.10			
5849	0.12	0.10	0.08	0.11	0.10	0.08	0.10	0.16	0.14
59010	0.11	0.15	0.21	0.11	0.18	0.25			
59080	0.21	0.13	0.09	0.09	0.41	0.08			
5920	0.12	0.28	0.20	0.11	0.29				
5921	0.24	0.42	0.34						
5990	0.11	0.09	0.27	0.22	0.08	0.11	0.12		
60001	0.25	0.46	0.29						
6170	0.39	0.28	0.33						
6183	0.13	0.24	0.16	0.17	0.12	0.18			
6202	0.48	0.28	0.24						
6256	0.24	0.21	0.34	0.21					
6262	0.16	0.13	0.15	0.36	0.20				

Category
- Digestive System
- Genitourinary System
- Immunity disorders

Figure 13: Priorities of clusters of encounters for episodes of care

Episode	Cluster 1	2	3	4	5	6	7	8	9
1533	0.20	0.26	0.29	0.25					
1534	0.46	0.21	0.33						
1536	0.19	0.31	0.30	0.20					
1540	0.47	0.22	0.31						
1541	0.26	0.26	0.27	0.21					
1623	0.17	0.22	0.30	0.32					
1625	0.46	0.16	0.38						
1744	0.25	0.25	0.50						
1748	0.29	0.35	0.35						
1820	0.12	0.16	0.20	0.11	0.15	0.17	0.10		
185	0.12	0.19	0.10	0.11	0.12	0.11	0.12	0.12	
1890	0.26	0.26	0.18	0.18	0.12				
1972	0.15	0.20	0.19	0.26	0.10	0.10			
1977	0.16	0.18	0.46	0.21					
1983	0.25	0.22	0.17	0.36					
1985	0.52	0.24	0.25						
2113	0.18	0.14	0.39	0.29					
2180	0.37	0.29	0.35						
2181	0.24	0.29	0.24	0.23					
2189	0.36	0.34	0.30						
220	0.32	0.22	0.18	0.28					
2252	0.09	0.16	0.45	0.30					
430	0.11	0.23	0.39	0.27					
431	0.20	0.15	0.24	0.41					
515	0.42	0.22	0.36						
566	0.15	0.69	0.16						
6822	0.22	0.24	0.38	0.16					
6827	0.19	0.35	0.21	0.25					
7802	0.13	0.10	0.09	0.08	0.16	0.09	0.11	0.09	0.14
78039	0.14	0.17	0.11	0.11	0.20	0.06	0.09	0.12	
7804	0.16	0.21	0.19	0.19	0.25				
7806	0.25	0.17	0.30	0.15	0.12				
78097	0.40	0.25	0.34						
78659	0.11	0.10	0.10	0.10	0.08	0.11	0.15	0.11	0.16
78791	0.19	0.16	0.21	0.44					
7999	0.32	0.36	0.16	0.16					
V5331	0.19	0.34	0.47						
V5332	0.43	0.38	0.19						
V552	0.37	0.32	0.30						
V553	0.37	0.36	0.27						
V5811	0.07	0.08	0.10	0.09	0.24	0.30	0.13		

Category
- Ill-defined conditions
- Injury
- Neoplasms
- Skin and subcutaneous tissue

Episode	Cluster 1	2	3	4	5	6	7	8	9
4660	0.09	0.10	0.21	0.27	0.13	0.20			
49122	0.18	0.12	0.36	0.12	0.11	0.12			
49322	0.29	0.22	0.24	0.25					
5070	0.17	0.49	0.14	0.20					
51881	0.20	0.10	0.09	0.27	0.06	0.10	0.17		
51884	0.35	0.22	0.43						
64231	0.27	0.48	0.25						
64241	0.29	0.23	0.21	0.27					
64251	0.31	0.38	0.32						
64421	0.16	0.18	0.15	0.12	0.10	0.14	0.15		
64511	0.29	0.28	0.42						
64891	0.13	0.11	0.10	0.11	0.10	0.11	0.15	0.20	
64893	0.24	0.15	0.15	0.31	0.15				
65221	0.19	0.32	0.16	0.13	0.19				
65421	0.12	0.08	0.10	0.12	0.11	0.11	0.13	0.11	0.12
65661	0.25	0.16	0.17	0.19	0.23				
65801	0.40	0.35	0.25						
65811	0.30	0.41	0.29						
65971	0.18	0.19	0.18	0.19	0.26				
65981	0.33	0.27	0.40						
66331	0.20	0.18	0.19	0.24	0.19				
66551	0.34	0.31	0.35						
8082	0.41	0.10	0.15	0.10	0.13	0.12			
82009	0.16	0.16	0.19	0.06	0.24	0.19			
82021	0.13	0.13	0.14	0.18	0.15	0.13	0.13		
99601	0.34	0.35	0.31						
99642	0.41	0.40	0.20						
99661	0.28	0.53	0.19						
99662	0.11	0.20	0.11	0.12	0.24	0.07	0.15		
99672	0.30	0.28	0.42						
99674	0.27	0.25	0.13	0.11	0.25				
9974	0.14	0.14	0.49	0.23					
99811	0.23	0.19	0.23	0.35					
99812	0.16	0.16	0.35	0.33					
99859	0.33	0.24	0.29	0.14					

Category
- Injury and Poisining
- Pregnancy
- Respiratory System

Figure 14: Priorities of clusters of encounters for episodes of care

5.3 Results of systemically pricing clusters of encounters using the proposed mathematical model

In this section, we first compare the results of pricing CBBP using the proposed two-stage linear programming pricing model vs. pricing done using the mean cluster FFS cost. In the following sections, the base (or benchmark) model considers the mean FFS cost (referred to as the base price) as the reimbursement price for a cluster of encounters. We then analyze the impact of the proposed reimbursement price for a cluster of encounters on the affordability and risk of overpayments using the comparison metrics defined in section 3.4 to understand the overall effect of the proposed pricing strategy on each of the 13 categories.

5.3.1 Results of re-allocating the total cost across all encounters within an episode of care on each category

Table 6: Comparison of the current total cost vs the proposed total cost for reimbursing encounters for a given category.

Rank	Category	Current Budget Under FFS System	Reallocated Budget Under Proposed Methodology	%change
1	Musculoskeletal System	$28,812,079	$25,988,227	-10.87
2	Circulatory System	$69,750,767	$69,350,822	-0.58
3	Injury	$8,614,013	$8,766,453	1.74
4	Neoplasms	$37,181,661	$36,504,132	-1.86
5	Poisining	$30,188,667	$29,264,702	-3.16
6	Immunity Disorders	$7,141,879	$7,393,408	3.40
7	Respiratory System	$17,372,520	$16,413,785	-5.84
8	Digestive System	$45,697,466	$46,932,466	2.63
9	Mental Disorders	$408,094	$428,499	4.76
10	Ill-defined conditions	$19,246,781	$20,209,118	4.76
11	Genitourinary System	$20,573,938	$21,602,623	4.76
12	Skin and Subcutaneous tissue	$1,438,317	$1,510,234	4.76
13	Pregnancy	$41,234,094	$43,295,814	4.76

Table 6 shows the comparison of the total cost for reimbursing all encounters across all episodes of care (under a given category) between the base model and the proposed methodology. Under the proposed methodology, the total cost for reimbursing all encounters under the most critical category i.e. Muscoskelatal disorders is 10.87% lower than the base model, thereby showing that the reimbursement price of disorders associated with the muscoskelatal system would be lowered thereby improving the affordability of these services. From Table 6 we can also see that the percentage change in total budget is in proportion to the level of criticality of the categories. For e.g., the least critical category, i.e. episodes of care and their clusters associated with Pregnancy will incur a higher reimbursement price as compared to the base model. The results indicate that the proposed methodology helps in reducing total costs for categories that are comparatively more expensive and overpriced. Also, in line with constraint (17) mentioned in section 3.3.2.4, the total cost for reimbursing all encounters across all categories remains unchanged between the base model and the proposed model thereby not affecting the overall total surplus of the payers or the providers.

Error! Reference source not found. from Table 6 shows that the proposed methodology helps in a systemic increase or decrease in the total reimbursement cost associated with each of the categories depending on their criticality i.e. highly critical categories have a reduced overall cost under the proposed methodology whereas less critical categories have an increased overall cost as compared to the base model. This implies that certain services within those categories (generally the most critical ones) will be offered at a lower cost as compared to the Mean FFS cost which will help in improving affordability.

5.3.2 Results of re-allocating the total cost across all encounters on average overpayments (from payer to provider) for each category

Table 7: Comparison of average amount of overpayments under the base model and the proposed methodology.

Rank	Category	Current Overpayments using Mean FFS Cost as the reimbursement price	Overpayments under the proposed methodology	%change
1	Musculoskeletal System	$3,430	$2,566	-33.67
2	Circulatory System	$2,355	$2,115	-11.33
3	Injury	$2,095	$1,975	-6.10
4	Neoplasms	$2,128	$1,872	-13.68
5	Injury and Poisining	$2,159	$1,926	-12.08
6	Immunity Disorders	$2,037	$2,127	4.24
7	Respiratory System	$1,979	$1,682	-17.67
8	Digestive System	$1,739	$1,848	5.90
9	Mental Disorders	$1,722	$1,971	12.62
10	Ill -defined conditions	$1,166	$1,462	20.28
11	Genitourinary System	$1,007	$1,312	23.22
12	Skin and subcutaneous tissue	$1,056	$1,337	21.02
13	Pregnancy	$729	$973	25.02

Table 7 shows that pricing clusters of encounters under the proposed methodology lowers the amount of average overpayments (33.67%) per encounter for the most critical category i.e. Muscoskelatal disorders. For the least critical category i.e. Pregnancy, there is an increased amount of average overpayments indicating that many encounters would be reimbursed at a price higher than the Mean FFS cost. There follows a systemic decrease in the amount of overpayments as compared to the base model depending on the criticality of the categories. Lowering overpayments would help in making services that are currently being highly overpaid more affordable.

5.3.3 Results of re-allocating the total cost across episodes of care under different cateågories

In this section, we show the results of reallocating the total cost of reimbursing all encounters for episodes of care under different categories.

5.3.3.1 Disorders related to Muscoskelatal systems

9 out of the 10 given episodes of care under the most critical category i.e. muscoskelatal system are subsidized under the proposed methodology. The average decrease in the reallocated budget among the subzidized episodes of care is 10.37%. Only the least critical episode of care (i.e. episode with ICD -09 code 7242) remains unsubsidized with an increase of 4.87% in the total cost for reimbursing all encounters under the given episode.

Table 8: Comparison of reallocation of total budget/revenue generation between the base and the proposed model for episodes of care related to Musculoskelatal system.

Episode	Subzidized	Current Budget	Re-allocated Budget	Episode Weight
72252	Yes	$4,481,310	$4,033,180	0.01504
7211	Yes	$2,372,130	$2,134,920	0.01427
7384	Yes	$2,932,490	$2,639,240	0.01194
7213	Yes	$1,576,890	$1,419,200	0.01191
7210	Yes	$2,588,160	$2,329,340	0.01158
7220	Yes	$2,641,530	$2,377,370	0.01104
72402	Yes	$5,399,050	$4,859,150	0.01053
72210	Yes	$3,563,290	$3,206,960	0.00998
73313	Yes	$2,874,870	$2,587,390	0.00751
7242	No	$382,359	$401,477	0.00365

5.3.3.2 Disorders related to Circulatory System

12 out of 28 episodes of care for disorders related to circulatory systems are subsidized under the proposed methodology. The average decrease in the reallocated budget among the subzidized episodes of care is 9.3 %. The episodes of care that are subsidized are the most critical episodes under the given category. The least critical episodes of care remains unsubsidized with an average increase of 4.17% in the total cost for reimbursing all encounters under the given episode.

Table 9: Comparison of reallocation of total budget/revenue generation between the base and the proposed model for episodes of care related to Circulatory System.

Episode	Subzidized	Current Budget	Re-allocated Budget	Episode Weight
4241	Yes	$4,732,440	$4,259,200	0.01750
42741	Yes	$983,032	$884,729	0.01355
44024	Yes	$1,419,350	$1,277,410	0.01322
4240	Yes	$1,464,300	$1,317,870	0.01258
4148	Yes	$2,744,630	$2,470,170	0.01227
4414	Yes	$3,801,490	$3,421,340	0.01174
44422	Yes	$812,896	$731,606	0.00993
44021	Yes	$2,062,600	$1,856,340	0.00915
4271	Yes	$3,446,710	$3,102,040	0.00914
41011	Yes	$2,829,260	$2,546,340	0.00789
40391	Yes	$935,638	$842,074	0.00763
4589	Yes	$684,323	$615,891	0.00751
42789	No	$5,035,320	$5,287,080	0.00688
42732	No	$3,524,710	$3,700,950	0.00681
4260	No	$1,845,940	$1,938,230	0.00677
42781	No	$3,960,920	$4,158,970	0.00612
4270	No	$946,900	$994,245	0.00582
42613	No	$593,526	$623,203	0.00578
43411	No	$2,469,890	$2,593,390	0.00577
45341	No	$1,393,560	$1,463,240	0.00574
41402	No	$1,114,890	$1,170,640	0.00569

41519	No	$4,870,880	$5,114,420	0.00563
43310	No	$4,342,950	$4,560,100	0.00513
43491	No	$7,009,760	$7,360,250	0.00489
42831	No	$764,479	$802,703	0.00436
4359	No	$3,961,920	$4,160,020	0.00425
4019	No	$919,763	$965,751	0.00362
4580	No	$1,078,690	$1,132,620	0.00352

5.3.3.3 Disorders related to Digestive System

Only 4 out of the 20 episodes of care for disorders related to digestive system are subsidized under the proposed methodology. The average decrease in the reallocated budget among the 4 subzidized episodes of care is 9.1 %. The episodes of care that are subsidized are the most critical episodes under the given category. The unsubsidized episodes of care witness an average increase of 4.85% in the total cost for reimbursing all encounters under the given episode.

Table 10: Comparison of reallocation of total budget/revenue generation between the base and the proposed model for episodes of care related to Digestive system.

Episode	Subzidized	Current Budget	Re-allocated Budget	Episode Weight
56969	Yes	$597,497	$537,747	0.00885
5570	Yes	$761,793	$685,614	0.00878
56081	Yes	$3,771,900	$3,394,710	0.00788
56089	Yes	$791,619	$712,457	0.00734
56211	No	$8,744,450	$9,020,230	0.00712
56210	No	$938,388	$985,308	0.00695
55321	No	$1,052,210	$1,104,820	0.00650
55221	No	$1,002,820	$1,052,960	0.00649
5550	No	$657,393	$690,262	0.00644
5770	No	$5,592,780	$5,872,420	0.00598
57400	No	$3,624,430	$3,805,650	0.00549
53081	No	$2,227,400	$2,338,770	0.00544
57410	No	$1,393,970	$1,463,670	0.00510

5609	No	$3,433,400	$3,605,070	0.00498
5789	No	$2,384,430	$2,503,650	0.00471
5781	No	$1,113,780	$1,169,470	0.00468
5400	No	$1,430,210	$1,501,720	0.00443
5409	No	$3,616,150	$3,796,950	0.00367
5589	No	$2,278,390	$2,392,310	0.00325

5.3.3.4 Disorders related to Neoplasms

Under the 4th most critical category of encounters i.e. Neoplasms, 14 out of the 26 episdoes of care subsidized under the proposed methodology. The average decrease in the reallocated budget among the 14 subzidized episodes of care is 9.1 %. The remaining 12 unsubsidized episodes of care witness an average increase of 4.99 % in the total cost for reimbursing all encounters under the given episode.

Table 11: Comparison of reallocation of total budget/revenue generation between the base and the proposed model for episodes of care related to Neoplasms..

Episode	Subzidized	Current Budget	Re-allocated Budget	Episode Weight
430	Yes	$1,134,250	$1,020,820	0.01528
2252	Yes	$1,292,090	$1,162,880	0.01203
566	Yes	$635,202	$571,682	0.01078
1625	Yes	$973,139	$875,825	0.00906
1540	Yes	$920,063	$828,056	0.00881
1541	Yes	$1,189,700	$1,070,730	0.00876
1985	Yes	$1,433,100	$1,289,790	0.00868
1744	Yes	$635,707	$572,136	0.00860
1623	Yes	$2,427,070	$2,184,360	0.00851
1890	Yes	$2,239,270	$2,015,340	0.00759
1536	Yes	$1,124,890	$1,012,400	0.00753
431	Yes	$1,747,480	$1,572,730	0.00738
515	Yes	$696,146	$626,531	0.00722
1748	Yes	$462,708	$416,437	0.00714

1533	No	$1,096,560	$1,151,390	0.00700
1534	No	$712,379	$747,998	0.00695
1977	No	$1,099,980	$1,154,980	0.00661
2113	No	$1,325,970	$1,392,270	0.00638
1983	No	$2,377,540	$2,496,420	0.00627
185	No	$5,987,680	$6,287,070	0.00572
1972	No	$1,000,110	$1,050,110	0.00553
1820	No	$1,512,330	$1,587,950	0.00479
2189	No	$1,826,870	$1,918,220	0.00384
2180	No	$874,129	$917,835	0.00375
220	No	$640,478	$672,502	0.00358
2181	No	$1,816,820	$1,907,670	0.00353

5.3.3.5 Disorders related to Immunity and Respiratory System.

Only 1 out of the 6 episodes of care related to Immunity disorders are subsized under the proposed methodology whereas only 3 out of the 6 episodes of care related to respiratory disorders are subsidized under the proposed methodology. In both the categories only the most ciritcal episodes of care are subsidized with an average decrease of 10% in the total cost while the total cost for less critical episodes of care increase by 5%.

Table 12:: Comparison of reallocation of total budget/revenue generation between the base and the proposed model for episodes of care related to Immunity and Respiratory System.

Episode	Subzidized	Category	Current Budget	Re-allocated Budget	Episode Weight
25070	Yes	Immunity disorders	$703,697	$633,328	0.01241
51884	Yes	Respiratory System	$1,039,330	$935,395	0.00971
51881	Yes	Respiratory System	$6,491,350	$5,842,210	0.00877
5070	Yes	Respiratory System	$4,651,570	$4,186,410	0.00857
25080	No	Immunity disorders	$2,671,180	$2,804,730	0.00689
25082	No	Immunity disorders	$859,919	$902,915	0.00660

25060	No	Immunity disorders	$548,485	$575,910	0.00608
2761	No	Immunity disorders	$1,898,260	$1,993,170	0.00518
4660	No	Respiratory System	$1,333,080	$1,399,730	0.00465
49322	No	Respiratory System	$1,685,810	$1,770,100	0.00369
49122	No	Respiratory System	$2,171,380	$2,279,940	0.00357
25012	No	Immunity disorders	$460,338	$483,355	0.00305

5.3.3.6 Disorders related to Injury and Poisining

8 out of the total 18 episodes of care related to Injury and Poisining are subsidized under the proposed methodoly. The average decrease in the total cost for the subsidized episodes of care is 9.07% wherease the increase in total cost for least critical episodes of care in the two categories is 4.98%.

Table 13: Comparison of reallocation of total budget/revenue generation between the base and the proposed model for episodes of care related to Injury and Poisining

Episode	Subzidized	Category	Current Budget	Re-allocated Budget	Episode Weight
V5332	Yes	Injury	$1,551,600	$1,396,440	0.01246
99661	Yes	Poisoning	$730,893	$657,804	0.01058
99674	Yes	Poisoning	$2,560,340	$2,304,310	0.01024
99601	Yes	Poisoning	$772,523	$695,271	0.00893
99662	Yes	Poisoning	$4,017,730	$3,615,950	0.00857
99859	Yes	Poisoning	$6,034,640	$5,431,180	0.00777
V5331	Yes	Injury	$303,503	$273,153	0.00748
9974	Yes	Poisoning	$2,106,640	$1,895,980	0.00728
V553	No	Injury	$1,072,300	$1,125,910	0.00688
82009	No	Poisoning	$3,856,150	$4,048,960	0.00685
V552	No	Injury	$1,122,690	$1,178,830	0.00681
99812	No	Poisoning	$688,548	$722,976	0.00660
99642	No	Poisoning	$471,953	$495,551	0.00658
82021	No	Poisoning	$5,116,360	$5,372,180	0.00634

99811	No	Poisoning	$1,075,080	$1,128,830	0.00512
99672	No	Poisoning	$1,556,880	$1,634,730	0.00510
V5811	No	Injury	$4,563,920	$4,792,120	0.00474
8082	No	Poisoning	$1,200,930	$1,260,980	0.00465

5.3.3.7 Other Disorders related to Genitourinary, Prenancy, Mental Disorders, Skin and Ill-defined conditions.

None of the 39 episodes of care under the least 5 critical categories of disorders are subsidized under the proposed methodology. Given the structure of our proposed model, the increase in the total cost for these episdoes of care is a trade-off for the decrease in the total cost for more critical episodes of care. The average increase in the total cost is approximately 5% across all episodes of care under the 5 given categories.

Comparison of the total budget and risk of overpayments between the proposed and the base model indicate that the proposed model helps in increasing the affordability and lowering the risk of overpayments for critical clusters of encounters. The increased affordability comes at the cost of increasing the reimbursement price and risk of overpayments for a less critical cluster of encounters. Therefore, it becomes inconclusive whether the systemic pricing of clusters of encounters increases the overall affordability of health care services, hence we use the weighted sum of the metrics as defined in section 3.4 to highlight the criticality of a cluster of encounters to understand the overall effect of the proposed methodology on the risk of overpayments and affordability of healthcare services.

5.3.4 Results of systemically pricing clusters of encounters on the overall system

In this section, we use the comparison metrics defined in Section 3.4 to understand the overall effect of using the proposed reimbursement price vs. the mean cluster cost as the reimbursement price for a cluster of encounters across the three episodes of care as shown in Table 14.

Table 14: Comparison of the proposed model vs the base model based on adjusted Comparison metrics

Adjusted average Overpayments ($)	Proposed Model	$275,940
	Base Model	$289,905
Adjusted affordability	$58,019	

As seen from Table 13, the adjusted total amount of overpayments, under the proposed methodology is less then the base model. This means that the effect of lowering overpayments for critical clusters of encounters is more effective than increasing overpayments of less critical clusters.

The overall risk of number of overpaid encounters under the proposed model is significantly lower than the base model thereby indicating that the effective number of overpaid encounters is lower as compared to the base model. The result shows that by lowering the number of overpaid encounters for critical clusters while increasing overpaid encounters for less critical episodes of care lowers the overall risk concerned with number of overpayments.

The value of the adjusted affordability ensures that using the proposed reimbursement price for a cluster of encounters increases the affordability of health care services as compared to using the mean FFS cost.

The proposed methodology for systemically pricing cluster of encounters increases the affordability of critical cluster of encounters by lowering the reimbursement price and reducing the risk of overpayments while increasing the reimbursement costs for less critical clusters of encounters. By using the features of an episode of care and their cluster of encounters in terms of the total average overpayments, the total FFS cost and the total number of encounters as an input, the AHP helps in identifying episodes of care and clusters of encounters that are more critical in terms of overall risk of overpayments and total cost in the given health care system. The proposed pricing approached is generalizable to any number of episodes of care, requiring minimal or no input from medical experts.

6. Conclusions

The proposed systemic pricing of clusters of encounters under the cluster based bundled payment system helps us in understanding the overall impact on the measure of affordability and overpayments on the healthcare system. Through our proposed methodology, we identified episodes of care where using the mean FFS cost included a high risk of overpayments and a higher reimbursement price. Pricing of these episodes of care and their clusters of encounters under the proposed methodology have a lower of risk of overpayments.

In addition to lowering the financial risk of overpayments as compared to base model, the proposed pricing mechanism also improves the affordability of the most expensive and overpriced medical services. The proposed methodology also helps in making services or clusters of encounters more affordable even among the least critical categories or the least critical episodes of care. Moreover the increase in the reimbursement prices for clusters of encounters or the reallocated budget for an episode of care is less than the projected increase in healthcare expenditure i.e. 5.5% from year 2017-2026.

The choice of weights used during the AHP process affects the way in which the proposed reimbursment price for cluster of encounters or the reallocation of the total budget among the episodes is determined. Modifying those parameters, as per the requirements of the provider or the payer can determine the new reimbursement costs without making any significant changes to the model.

By maintaining the total cost for reimbursing encounters in the benchmark and the proposed model equal, the proposed methodology does not affect the surplus for both the payers and the providers. Using AHP to identify the most critical episodes of care and their clusters of encounters enables us to generate more revenue from less critical episodes of care or clusters of encounters by offering services at a marginal increased cost as compared to the Mean FFS cost and generate less revenue from the most critical episodes of care.

The present study uses parametric values for the allowable marginal change in the total budget and the reimbursement prices. The results shown in this study heavily depend on the maximum allowable increase or decrease in the reimbursement prices for clusters of encounters and episodes of care. Future work will focus on adjusting the values of these bounds as a function of the criticality of the cluster of encounters will result in a more systematic adjsutment of the reimbursement price and may result in reducing the financial risk and improving the affordability even further.

This study provides a pricing framework to help the providers and the payers reach on a contractual agreement on the reimbursement price for a given episodes of care. Given that the overall surplus of the payers and the providers remains unaffected over the entire range of episodes, we expect expert medical practioners to identify avoidable and unecessary services for a given episodes of care which would ultimately help in reducing the overall healthcare costs.

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8. Appendix

Our study proposes a systemic pricing of pricing clusters of encounters in a cluster-based bundled payment system. The proposed methodology takes the input of insurance claims records extracted through 5 different SQL queries, each fetching data across different tables in the FLHSA database. The data used in this study comprises of HIPPA compliant 30,271 insurance claims records (encounters) of patients across 153 most expensive episodes of care for the year 2007 across all providers in upstate New York. The extracted data is then fed into the clustering and classification algorithms under the Clustering Based Bundled Payment system proposed by Singh [13]. In this appendix, we present and analyze the data in a more an interpretable form which can prove useful to the healthcare-based research work using claims data.

Each observation in the dataset represents an encounter. Each encounter has 20 attributes related to the episode of care, the total encounter cost and the biographical data of the patients. Table 15

Table 15: Variables and their description

Category	**Category for an Episode of Care**
Episode	ICD -09 code of an Episode of Care
Count	Total number of encounters in an Episode of Care
Current.Budget	Total cost of reimbursing all encounters in an Episode of Care
Current.Overpayments	Average amount of Overpayments in an episode of care
AverageCurrentCost	Average FFS cost for an episode of care
cluster	Cluster ID for an episode of care
enc_begin_date	Start date of an encounter
enc_end_date	End date of an encounter
enc_selected_primary_diagnosis_code	Encounter's primary diagnosis code
member_sex	0 - Female, 1 - Male
member_dob	Date of Birth of the patient
Total_paid_cost	Encounter's FFS Cost
age	Mean population age in an episode of care

lengthOfStay	Mean length of stay in an episode of care
Male.x	%Male Population for an Episode of Care
LengthofStay	Mean length of stay for a cluster
Count.y	Number of Encounters in a cluster
Male.y	%Male Population for a cluster
Age	Mean population age in a cluster
Current.Overpayments	Current average overpayments in a given cluster

Each encounter belongs to only one episode of care whereas an episode of care may constitute of one or more encounters. The start (enc_begin_date) and end date (enc_end_date) of an encounter are shifted by 15 days to prevent any usage of data to backtrack to the details of the patient. Biographical data of the patients includes age and gender. Males constitute 37.4% of the insurance claims records in this study whereas females constitute 62.6%. The mean length of stay for an encounter is 4.49 days with the maximum being 22.375 days and minimum being 0.71 days.

Data for an episode of care is grouped into multiple clusters using the methodology proposed by Singh [13]. The data for each of the encounters is first aggregated for each episode of care to provide the necessary information which is then used to determine the criticality of the given episodes of care. Since we do not require all the necessary information from Table 15, we first subset the dataset containing the necessary information related to the episode of care consisting of the total budget, average overpayments, number of encounters and average cost per encounter. Similar to an episode of care, we select features for a cluster of encounters like mean FFS cost, average overpayments and average number of encounters to rank clusters of encounters in an episode of care.